NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

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SALTS IN IRRIGATION AGRICULTURE

by

F.Penman
Commonwealth Scientific and Industrial Research Organization
Melbourne, Australia

INTRODUCTION

1. Establishment of irrigation not only changes the whole water regime of an area but may also have far-reaching effects through the medium of salts. All irrigation waters contain salts and many soils on which irrigation is desired either contain significant amounts or are underlain by salty substrata or are potentially subject to the effects of saline groundwater. This means that it is necessary to understand complex situations in which soils, plants and animals may come under the influence of salts from several sources and fluctuating in concentration and composition. Fluctuations may be short term, depending on such things as timing of irrigations and rainfall, the nature of the under-drainage, cropping and management; and long term, depending on continual accession of salts from irrigation water, rise of level of underground water, diffusion of salts in underground water, and other factors.

2. Except for mechanical operations like skimming off surface incrustations of salt, the determinants of salt movement in soils and plants and offering means for controlling it are concerned with water movement. This is because many salts are soluble in soil-water and move with it. Detailed knowledge of the water regime in the soil, in the plants supported by it, and in the strata underlying it, is therefore a prerequisite to understanding salt movements and accumulations. The differing soil-water gradients prevailing at different times in irrigated land determine such important matters as whether processes operating, some in conflict with others, will result in a net reduction of salts, i.e. leaching, in the root zone, or in an accumulation of salts there and perhaps at the soil surface. Much valuable information on plant-water relationships has been assembled by U.N.E.S.C.O.[1]

COMPOSITION OF IRRIGATION WATER

3. It is only in comparatively recent years we have realized that the chemical composition of irrigation water must be known in some detail and matched with requirements defined by chemical analysis of the soil if good conditions for water movement are to be maintained in any soil other than those consisting virtually of sand. Soils containing colloidal material have an "exchange capacity" for cations, i.e. calcium, sodium, magnesium, potassium and hydrogen. Salts of sodium in high proportions in irrigation water, or in the soil-waters

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1 U.N.E.S.C.O., Plant-water relationships in arid and semi-arid conditions, Arid Zone Res. 16, 1961.

circulating during normal processes of soil formation before the advent of irrigation, may lead to sodium occupying such a proportion of the "exchange" positions on the soil clay that is rated as a "Sodic" colloid. Such colloids usually are readily deflocculated by waters low in salts. Hence soils containing clay of this sort show low infiltration rates, low permeability and poor aeration and are difficult to cultivate. Control of these difficulties by appropriate choice of the salt content of irrigation water is discussed in paragraphs 5 and 6.

4. The selective mechanisms operating for absorption of water and solutes by plant roots are such that little salt is taken from the soil. Together with evaporation of water at the soil surface, transpiration through plants leads to concentration of salts in the soil solution, commonly to an extent varying from twice to more than 10 times their concentration in the irrigation water used. Such salts, especially if they accumulate in the root zone as a result of repeated irrigations, as indicated in paragraph 2, impair plant growth and may destroy it. They do this by osmotic effects, working against the plant mechanisms for water uptake, and by direct toxic effects of certain ions which enter the plant through the roots in small quantities and may accumulate in certain of its tissues. The combined effects are such that very sensitive crops, like lettuce and beans, will often fail on poorly drained soil after a single irrigation with water containing 850 to 1,000 parts per million (p.p.m.) of dangerous salts.[2] Toxic ions include chloride, sulphate, bicarbonate, borate and sodium, and others, including calcium and magnesium, may give toxic effects in particular plants if present in high concentration in the soil solution. Lithium, at a concentration of less than 0.1 p.p.m. in irrigation water can cause leaf burning and defoliation of citrus,[3] while boron may give some toxic effects above about 0.5 p.p.m. Fluorides and salts of molybdenum and selenium may be absorbed by plants from some soils and irrigation waters without any apparent harm, but such plants may prove harmful when fed to animals. When lithium and boron are in evidence, there is obvious need for great care in reusing drainage waters for irrigation.

5. The need for detailed knowledge of the chemical composition of irrigation waters is evident from paragraphs 3 and 4. Among the many systems which have been used for assessing the worth of waters for irrigation, that developed by the United States Salinity Laboratory[4] has been widely used. It classes waters according to salinity hazard, sodium hazard and boron and bicarbonate[5] content. The steps required for evaluation of irrigation waters along these lines are very clearly set out by the United States Department of Agriculture.[6]

6. Although procedures such as those referred to in paragraph 5 are of great value, there is a danger, in using the quantitative limits for different classes of waters, that the qualifying information. . .

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2 Spurling, M.B., Water from bores, wells and streams - suitability for irrigation and household use, J.Agric.South Aust., 65: 492-6, 499,(1962).
3 Fireman, M., Relation of irrigation water quality to soil problems, Trans. 4th Congr. I.C.I.D., S: 13.31-13.43 (1960).
4 U.S. Salinity Laboratory, Diagnosis and improvement of saline and alkalic soils, U.S.D.A. Handbook 60 (1954).
5 Eaton, F.M., Significance of carbonates in irrigation waters, J. Agr. Res. 64: 357-399 (1942).
6 Wilcox, L.V., Determining the quality of irrigation water, U.S.D.A. Agr. Inf. Bull. 197 (1958).

which is a summation of wide experience, may be neglected. For example, while it may be a fairly general rule that water containing up to, say, 3,500 p.p.m. of salts may be considered for some form of irrigation, it is recorded[7] that waters containing up to 8,000 p.p.m. are acceptable in several countries. Irrigation, persisting for thousands of years in North Africa and Arabia, with waters of this salinity, is however carried out under conditions of perfect natural under drainage and water management such that ample leaching of salts is ensured. Compare with the South Australian experience on poorly drained soil (paragraph 4) this illustrates clearly the inter-relation between irrigation and drainage, which is so important when salinity is involved. The chief qualifying assumptions made in the United States assessment of water quality[6] are that: (a) the soil will take water readily, (b) the soil will drain well; (c) sufficient irrigation water will be applied to prevent salt accumulation in the root zone; and (d) crops of proper salt and boron tolerance will be planted. Considerations of this kind must be kept clearly in mind in interpreting the results of water analysis, along with intensity and amount of rainfall and level and salinity of underground water. A recent significant paper[8] which considers the irrigation of soil as a column process, indicates how refinements may be made in the interpretation of water analyses and predictions made of the effect of water on soils.

DRAINAGE AND LEACHING REQUIREMENTS

7. It is essential that, following irrigation or rainfall, water move downward through the root zone at a rate sufficient to satisfy the aeration requirements of the plant roots and in quantity sufficient to keep salt concentration in the root zone down to that consistent with plant tolerance. The concept of "leaching requirement", the proportion of irrigation water that needs to drain to below the root zone, is a valuable approach.[9] Although the soils are light and irrigation waters of good quality, it is now recognized in South Australia "that management of citrus trees should aim at applying 10 to 15% excess water above tree irrigation needs, specifically to attain adequate leaching of salts.

EFFECT OF SALTS ON PERMEABILITY OF IRRIGATION SOILS

8. In paragraph 3, prospects were indicated for controlling de-flocculation of sodium clay by means of suitable choice of salt content of irrigation water, thus ensuring that the soil will have the best permeability and related properties its physical and chemical constitution will allow. There are indications[11] that it should be possible to maintain the permeability of a soil, irrespective of its sodicity, by using a sufficiently strong salt solution. This is best done with a solution of a calcium salt to maintain flocculation and to displace sodium from the exchange system of the colloid. For soils within the ordinary range of sodicity, gypsum has sufficient solubility for this purpose.

7 Kovda, V.A., Tolerance of plants to minerals in solution in irrigation water, Trans. 4th Congr. I.C.I.D. 5: G13.1-G13.28 (1960).
8 Bower, C.A., Prediction of the effects of irrigation waters on soils, Arid Zone Res., 14: 215-221 (1961)
9 Reeve, R.C., The relation of salinity to irrigation and drainage requirements, Trans. 3rd Congr. I.C.I.D. 10.175-10.187 (1957).
10 Spurling, M.B., Soils used and pest and disease situations have important bearing on citrus fruit quality, Citrus News, 38: 78-9 (1962).
11 Quirk, J.P., Effect of electrolyte concentration on soil permeability and water entry in irrigation soils, Trans. 3rd.Congr.I.C.I.D.8 115-8.123(1957)

9. When an irrigation water of significant salinity is used for a time and then another, much less saline, replaces it, deflocculation will then take place, so that permeability quickly falls. A well-known instance of this, in Arizona, where the soil "froze" under such conditions, has been examined in the light of recent knowledge,[11] which indicates that the trouble could have been prevented by continuing to use, for a time, a small proportion of the more saline water, blended with the less saline supply.

RECLAMATION OF SODIC SOILS BY LIMITED USE OF GYPSUM

10. Gypsum may be needed in large quantities per acre if it is desired to replace most of the exchangeable sodium in heavy sodic soils by calcium. It has been reported[12] that treatment of a poorly drained, saline-sodic soil with as much as 27 tons of gypsum per acre was effective only after a long period of leaching. In the Riverina plains of south-eastern Australia, there are many heavy textured soils with significant sodicity. Difficulties of pasture establishment on an important proportion of these soils have been such that often several years have been necessary for the few seedlings which emerged after sowing to propagate a good cover. Typical soils of this kind require about 2.5 tons of gypsum per acre to replace exchangeable sodium by calcium in the top 3 inches. An alternative approach suggested[13] is to add gypsum to the irrigation water to prevent deflocculation. This can be achieved with only 0.25 ton per acre, at a concentration of 800 p.p m. in a 3 inch irrigation. Without such treatment, deflocculation follows irrigation with water of low salinity and the resulting clay suspension settles out on the soil surface as a clay wash. On drying, this forms a hard crust, often impenetrable by seedlings. (Figure 1) In one instance, only one plant emerged from 30,000 viable seeds of white clover (Trifolium repens).

11. If only the first irrigation after dry sowing is treated with gypsum, a 60% emergence of subterranean clover (T. subterraneum), the main pasture species of the region, can be expected. Increased yields per plant are also obtained, the gypsum giving a more friable soil surface and increased rate of water entry, thereby allowing earlier aeration of plant roots after irrigation or rain (**Figure 2**). Once established, pasture species continue amelioration processes in the soil along well-known lines.[14] A recent booklet[15] describes a simple test, to show whether satisfactory response to gypsum is obtainable with a particular soil, and the construction and operation of a gypsum-dissolving machine the essential components of which are a centrifugal pump and a cyclone made from a 44 gallon drum.

RECLAMATION OF SMALL SALT-AFFECTED AREAS FOR PASTURES

12. Since 1960, investigations in northern Victoria[16] have sought to

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12 Brauson, R.L., and Fireman, M., Reclamation of an "impossible" alkalic soil, Trans. 7th Int. Congr. Soil Sci., 1: 543-552 (1960).
13 Davidson, J.L., and Quirk, J.P., The influence of dissolved gypsum on pasture establishment or irrigated sodic clays, Aust. J. Agr. Res. 12:100-110 (1961).
14 Kelley, W.P., Alkalic Soils, Reinhold, New York (1951).
15 Anon., Dissolved gypsum for irrigation soils, Com. Sci. & Indust. Res. Org. and Dept. Agric. New South Wales, Melbourne (1962).
16 Garland, K.R., and Jones, G.O., Reclamation of saline soils by ponding and aqifer-pumping, submitted for Aust. J. Exp. Agric.An.Husb.(1962).

assess a rapid and simple method of reclaiming comparatively small areas of salty and salt-affected heavy soils of the Riverina plain. The method is applied where pressure water in an aquifer underlying the clays, which often drain well vertically, may rise in a bore (penetrating to the aquifer) to such a level that it may be pumped away to drains. Ponding of irrigation water on the surface before and during pumping and the lowering of water table associated with the relief of upward pressure from the aquifer, facilitate a substantial leaching of salt. Soil salts on the main site examined consist very largely of sodium chloride. During 10 days of ponding, sodium chloride in the surface 6 inches of soil decreased from 1.60% to 0.05%, with only 56 hours of pumping by a 1½in or 2 in pump. Corresponding changes in the top 12 inches were from 1.82% to 0.32%. Such leaching was not attainable by other means because of the highly saline (about 5% sodium chloride) water table from 1 to 3 ft below the soil surface in this area, which in 1960 carried no worthwhile vegetation - only scattered samphire. Since leaching, the area of 2½ acres concerned has grown millet followed by successful establishment of perennial pasture which carried 4½ sheep per acre between August 1961 and April 1962. Pumping has not been necessary since 1960. The bore for pumping was put down 24 ft by hand. While this method, seeking to miminize pumping costs, quantity of discharged salty water (containing about 3% sodium chloride in this case) and quantity of leaching water, will require time for adequate evaluation, it shows promise, particulary for intractable salt-affected areas on otherwise productive farms.

FOLIAR ABSORPTION OF SALTS FROM SPRINKLER IRRIGATION

13. When high evaporation rates prevail in summer, sprinkler irrigation may induce leaf burn of plants, and even defoliation, as the result of salt deposition on the foliage. Californian waters which cause trouble are in the moderate to high salt range.[3] Under conditions of strong evaporation, low water application rate and intermittent rotating sprinklers, it has been found in South Australia,[17] however, that salt damage to citrus leaves may occur with water containing less than 290 p.p.m. of dissolved salts.

SELECTION OF PLANTS FOR SALT TOLERANCE

14. In the selection and breeding of varieties of plants for salt tolerance under specific conditions of climate, soil and other variables, a great amount of field testing may be necessary. As soil salt concentrations, especially in the surface soil, vary seasonally, there may not be sufficient salt concentration in some years to show differentiation in the tolerances under test. A recent report[18] describes a rapid test, based on health ratings of intact plants subjected to a brief salinity stress induced by sodium chloride. This requires only 7 days under glasshouse conditions. The work was done with medics but offers a simple procedure for wider application.

CONCLUSION

15.(a) While it has been possible to mention here only a few aspects

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17 Spurling, M.B., Spray irrigation of citrus, J.Agric. South Aust. 65; 250-4 (1962).

18 Greenway, H., and Andrew, W.D., A screening technique to predict field behaviour of medics on saline soil, Aust. J. Exp.Agr. An.Husb. 2 (7) (in press)(1962).

of salts in irrigation, a great wealth of experience from all over the world has recently been brought together through international organizations. A number of international congresses[19, 20, 21, 22] have reviewed this subject during the last 5 years. A comprehensive assembly of relevant material from these and other sources is in hand by U.N.E.S.C.O. and F.A.O., in the form of an International Source book.

(b) In the meantime, there is a need for further research, perhaps along the lines of a recent review,[23] and a special need for those concerned with the selection of lands and waters for irrigation and with administration of irrigation projects, to be aware of the broad outlines of recent scientific and engineering investigations in the field. Salty and salt-affected lands are the major problems of irrigation. It is recorded[24] that one country with much irrigation loses nearly as much land every year by salinization following irrigation as is reclaimed for agriculture. Means to avert salt problems are now known for a wide variety of conditions. The time for over-simplified or casual approaches is past. Administrators who read, for example, the discussion and general report on "Tolerance of Plants to Minerals in Solution in Irrigation Water and in Soil"[21] probably will wish to ensure that an appropriate integration of the skills of engineers, economists and scientists, including the soil chemist, water analyst, agronomist, plant physiologist and hydro-geologist, are brought to bear on their irrigation problems.

Figure 1.

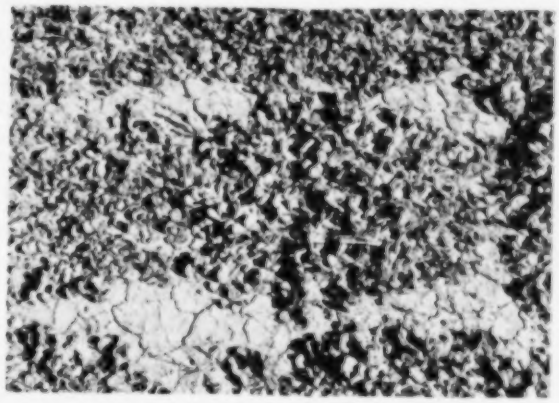

Figure 2

Establishment of subterranean clover pasture six months after sowing on a sodic clay - irrigated with untreated water (Fig. 1) and with water containing 860 p.p.m. of dissolved gypsum, during the first stages of establishment, thereafter with untreated water **(Fig.2)** .

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19 I.C.I.D. Trans. 3rd Congr., Inter-relations between irrigation and drainage. (1957)

20 First Inter-soc. Conf. Irrig. and Drainage, Can man develop a permanent irrigation agriculture? U.S. Nat. Committee. I.C.I.D. (1957).

21 U.N.E.S.C.O., Salinity Problems in the Arid Zones, (1961).

22 I.C.I.D., Trans. 4th, Congr. (1960).

23 Hagan, R.M., and Vaadia, Y., Selecting measurements and data in water-soil-plant relations experiments, Reference 2: 331-335 (1961).

24 Repp, G., The importance of biological factors in the improvement of saline soils, Reference 27: 295-297 (1961).

1413 E - Nov. 1962 - 1,600